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RESEARCH MEMORANDUM

AN INVESTIGATION OF THE LOW-SPEED LONGITUDINAL STABILITY

CHARACTERISTICS OF A SWEPT-WING AIRPLANE MODEL

WITH TWO MODIFICATIONS TO THE WING-

ROOT PLAN FORM

By William B. Kemp, Jr.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

A wind-tunnel investigation has been made to determine the effects of two wing-root leading-edge plan-form modifications, namely, a notched leading-edge fillet and a rounded leading-edge fillet, on the low-speed longitudinal stability characteristics of an airplane model having a 50.7° sweptback wing. Either fillet modification produced a rearward shift of the aerodynamic center of the wing-fuselage combination which was only about half as great as that which would be predicted from geometric consideration of the change in the exposed-wing plan form with no change in fuselage carryover effect assumed. A reduction in the variation with lift of the effective downwash at the tail at low lift coefficients was produced by either fillet modification and an increase in the contribution of the horizontal tail to stability resulted. A loss of stability at high lift coefficient, observed with the basic wing, was made considerably less severe by either fillet modification and was essentially eliminated in the case of the complete model with the rounded leading-edge fillet. The rounded leading-edge fillet produced a reduction in drag due to lift and caused increased lift-drag ratios. The tail-off maximum lift coefficient was increased by the rounded leading-edge fillet and decreased by the notched leading-edge fillet. The trimmed maximum lift coefficient, however, was not affected by the rounded leading-edge fillet and was decreased by the notched leading-edge fillet.

INTRODUCTION

In the design of airplanes with variable-sweep wings the problem of filleting and sealing the wing-fuselage juncture may have many solutions,

some of which involve considerable mechanical complication. Some forms of wing-root leading-edge fillet which have been conceived to reduce mechanical complication involve wing plan forms which depart at high sweep angles from the usual family of swept-wing plan forms. Inasmuch as an unknown region of the fuselage would be effective in carrying lift between the wing panels, some difficulty is anticipated in estimating the aerodynamic center location of wing-fuselage combinations incorporating such leading-edge fillets.

An investigation of the low-speed longitudinal stability characteristics of a swept-wing airplane model has been made in the Langley 300 MPH 7- by 10-foot tunnel to determine the effect of two wing-root leading-edge modifications which may be applicable to airplanes with variable-sweep wings. A model that had previously been used in an investigation of a variable-sweep airplane design was used for the tests reported herein. The longitudinal characteristics obtained in the variable-sweep investigation are reported in reference 1.

SYMBOLS

The aerodynamic forces and moments are presented in the form of standard NACA coefficients based on the plan form of the basic wing shown in figure 1. This plan form incorporates a rectangular center section having a semispan of 5.60 inches. The moment reference center is located at 24.2 percent of the mean aerodynamic chord of the basic wing plan form. The symbols used are defined below:

C_L lift coefficient, Lift/qS

C_D drag coefficient, Drag/qS

L/D lift-drag ratio

C_m pitching-moment coefficient, $\text{Pitching moment}/qS\bar{c}$

q free-stream dynamic pressure, $\rho V^2/2$, pounds per square foot

S wing area (basic wing), sq ft

$\bar{c}$ mean aerodynamic chord of basic wing, $\dfrac{2}{S}\displaystyle\int_{0}^{b/2} c^2 dy$, ft

c local streamwise chord, ft

y spanwise distance from plane of symmetry, ft

b wing span, ft

V free-stream velocity, ft/sec

A aspect ratio, b^2/S

ρ mass density of air, slugs/cu ft

α angle of attack of thrust line, deg

i_t horizontal tail incidence relative to thrust line, deg

ϵ effective downwash angle at tail, deg

APPARATUS AND METHODS

Description of Model

A three-view drawing of the model used in this investigation, together with a table of physical characteristics, is presented in figure 1. The model was installed on a single faired support strut under the fuselage. Details of the basic wing and the two modified leading-edge fillets are given in figure 2. The wing surface with each of the modified fillets was faired so that the leading-edge radius at the wing-fuselage intersection was considerably larger than that of the basic wing. The wing incidence measured in a streamwise direction was zero and the moment reference center was located at 24.2 percent of the mean aerodynamic chord of the basic wing.

Jet-engine ducting was simulated on the model by the use of an open tube having an inside diameter equal to that of the jet exit and extending from the nose to the jet exit.

Tests

The tests were made in the Langley 300 MPH 7- by 10-foot tunnel at a dynamic pressure of 34.15 pounds per square foot, which corresponds for average test conditions to a Mach number of 0.152 and a Reynolds number of 2×10^6.

During the tests, no control was imposed on the air-flow quantity through the jet duct. It is probable, therefore, that the inlet-velocity ratio had values somewhat less than 1.0.

Corrections

The angle of attack, drag, and pitching-moment results have been corrected for jet-boundary effects computed on the basis of unswept-wing theory by the method of reference 2. Independent calculations have shown that the effects of sweep on the above corrections are negligible. All coefficients have been corrected for blocking by the model and its wake by the method of reference 3.

Corrections for tare forces and moments produced by the support strut have not been applied. It is probable, however, that the significant tare corrections would be limited to small increments in pitching moment and drag. Vertical buoyancy on the support strut, tunnel airflow misalinement, and longitudinal pressure gradient have been accounted for in computation of the test data.

RESULTS AND DISCUSSION

Presentation of Results

The longitudinal aerodynamic characteristics of the test model with the basic wing, the notched leading-edge fillet, and the rounded leading-edge fillet are presented in figures 3, 4, and 5, respectively. The aerodynamic coefficients for all leading-edge configurations were based on the wing area and mean aerodynamic chord of the basic wing plan form. This plan form was assumed to incorporate a rectangular center section having a semispan of 5.60 inches or 16.5 percent of the wing semispan to represent the region of the wing covered by the fuselage. (See fig. 1.) As an aid in analysis of the results, the effective downwash angles at the tail, the drag polars, and the lift-drag ratios are presented in figures 6, 7, and 8, respectively.

Stability at Zero Lift

The tail-off and tail-on aerodynamic-center locations at zero lift were determined for each fillet configuration from measurements of the slopes of the faired pitching-moment curves. The results are presented in table I in terms of percent mean aerodynamic chord of the basic plan form and also of plan forms which account for the fillet modifications. Inasmuch as the amount of fuselage area which is effective in carrying lift between the wings is not obvious for the fillet shapes considered, two sizes of center section were assumed in calculating the mean aerodynamic chord of each modified wing. The large center section was identical with that assumed for the basic wing and the small center section included only the area between the actual wing-fuselage intersections of each modified wing.

The results presented in table I for the tail-off conditions indicate that each fillet modification produced a rearward shift in aerodynamic center of about 2 percent of the mean aerodynamic chord of the basic wing. Relative to the mean aerodynamic chord of the actual filleted plan form, however, the aerodynamic center of each filleted wing was about 2 percent of the mean aerodynamic chord forward of that of the basic wing when the large center sections were assumed and considerably farther forward when the small center sections were assumed. It appears, therefore, that the rearward aerodynamic-center shift produced by either fillet modification was only about half as great as that which would be predicted from geometric consideration of the change in the exposed-wing plan form with no change in fuselage carryover effect assumed. This result is apparently associated with the fact that the region of a swept wing in the vicinity of its apex carries relatively low lifting pressures. It is interesting to note at this point that examination of the tail-off lift curves of figures 3 to 5 shows that the fillet modifications produced no measurable change in lift-curve slope $\partial C_L/\partial \alpha$ although the wing area was reduced by at least 3 percent.

The aerodynamic-center locations for the tail-on conditions presented in table I indicate that the rearward aerodynamic-center shifts produced by the fillet modifications were somewhat greater than those for the tail-off conditions. With the tail on, the aerodynamic-center locations in percent mean aerodynamic chord of the filleted plan forms with large center section were practically equal to that of the basic wing.

One reason for the greater aerodynamic-center shift produced by the fillets with tail on than with tail off is evident in figure 6, in which the effective downwash angle at the tail is plotted against angle of attack for the three wing configurations. The downwash angles were calculated from the measured pitching-moment data on the basis that the downwash angle was equal to the sum of the angle of attack, the tail incidence, and the increment of tail incidence required to make the pitching-moment coefficient equal to that measured with the tail off. The data of figure 6, indicated that, for low angles of attack, the downwash slope $\partial \epsilon/\partial \alpha$ was less for the two fillet configurations than for the basic wing. The tail contribution to longitudinal stability was thus increased by the fillets and a small additional rearward movement of the aerodynamic center resulted.

Variation of Stability with Lift Coefficient

Although the preceding discussion was based on observations at zero lift, the trends pointed out were apparent at any lift coefficient below about 0.4. At higher lift coefficients the model with the basic wing plan form exhibited irregularities in the lift and pitching-moment

characteristics (fig. 3) which are typical of thin sweptback wings on
which a leading-edge vortex type of flow exists. These irregularities
are characterized by an increase in lift-curve slope and static sta-
bility at moderate lift coefficients, followed by a marked decrease in
static stability at high-lift coefficients. Values of $\partial C_m/\partial C_L$ meas-
ured from figure 3 are about 0.2 more positive at $C_L = 0.85$ than
at $C_L = 0$ for both the tail-off and tail-on conditions.

Comparison of the pitching-moment curves of the filleted configu-
rations with those of the basic wing shows that considerable improvement
of the pitching-moment characteristics was effected by either fillet
arrangement. For the tail-off conditions, both fillet arrangements
increased by about 0.15 the lift coefficient at which the marked reduc-
tion in stability occurred. In addition, the degree of stability reduc-
tion observed at high lift coefficients was considerably less for the
rounded leading-edge fillet than for the basic wing.

With the horizontal tail on, both fillet configurations exhibited
much smaller variations of stability with lift coefficient than were
observed with the basic wing. In the case of the rounded leading-edge
fillet, the stability was practically constant throughout the entire
lift-coefficient range. The downwash variations presented in figure 6
show that, at angles of attack above 12°, the downwash slope $\partial \epsilon/\partial \alpha$ was
noticeably lower for the rounded leading-edge fillet than for the other
configurations. The resulting increased tail contribution to stability
at high lift coefficients was a factor in producing the superior sta-
bility characteristics of the complete model with the rounded leading-
edge fillet.

A possible explanation of the improved characteristics produced by
the leading-edge fillet arrangements may be the effect of the fillets
on the leading-edge vortex flow around the wing. If it is assumed that
the leading-edge vortex has its origin at the forwardmost point of a
swept leading edge, the fillet arrangements investigated would be
expected to result in a more outboard location of the entire vortex
pattern. Studies of the vortex-flow phenomenon have shown that at a
sufficiently high-lift coefficient the leading-edge vortex trails stream-
wise at a position inboard of the tip resulting in a loss of lift over
the tip region and a consequent reduction in stability. An outboard
movement of the vortex pattern resulting from the leading-edge fillets
would be expected to reduce the severity of this stability change at
high-lift coefficients or increase the lift coefficient at which the
stability change occurs.

Lift and Drag Characteristics

The drag polars of the three wing-fuselage combinations are repro-
duced in figure 7 for ease of comparison. The drag polar with the
notched leading-edge fillet was practically identical with that of the
basic wing at all lift coefficients up to the maximum for the notched
fillet. The minimum drag coefficient was slightly increased by this
arrangement. With the rounded leading-edge fillet a considerable reduc-
tion in drag due to lift was observed with no increase in minimum drag.
It is possible that more leading-edge suction was realized on the inboard
portion of this configuration than on the highly swept leading edge of
the basic wing. The effect of the reduction in drag due to lift on the
lift-drag ratio is shown by figure 8. The configuration with the rounded
leading-edge fillet produced a higher maximum lift-drag ratio than the
basic wing and exhibited higher lift-drag ratios at all lift coefficients
above that corresponding to maximum lift-drag ratio.

The tail-off maximum lift coefficient obtained with the rounded
leading-edge fillet was somewhat higher than that of the basic wing
(figs. 3 and 5). A comparison of the trimmed maximum lift coefficients,
obtained by extrapolating to $C_m = 0$ the envelope of maximum lift coef-
ficients for the three tail conditions, indicates that, for the center-
of-gravity location considered, the trimmed maximum lift coefficients
were practically equal for the basic wing and the rounded leading-edge
fillet. The notched leading-edge fillet caused a reduction in maximum
lift coefficient for both the tail-off and trimmed conditions.

CONCLUSIONS

The results of an investigation to determine the effects of a
notched leading-edge fillet and rounded leading-edge fillet on the low-
speed longitudinal stability characteristics of a swept-wing airplane
model have led to the following conclusions:

1. The rearward shift of the aerodynamic center of the wing-fuselage
combination produced by either fillet modification was only about half as
great as that which would be predicted from geometric consideration of
the change in the exposed-wing plan form with no change in fuselage
carryover effect assumed.

2. Either fillet modification produced a reduction in the variation
with lift of the effective downwash at the tail at low-lift coefficients
and an increase in the horizontal tail contribution to stability resulted.

3. A loss of stability at high-lift coefficients observed with the
basic wing was made considerably less severe by either fillet modification

and was essentially eliminated in the case of the complete model with the rounded leading-edge fillet.

4. The rounded leading-edge fillet produced a reduction in drag due to lift resulting in increased lift-drag ratios.
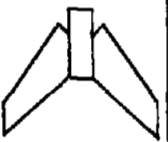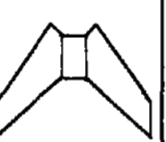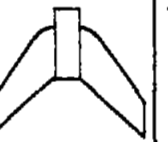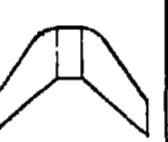
5. The rounded leading-edge fillet increased the tail-off maximum lift coefficient but did not change the trimmed maximum lift coefficient for the center-of-gravity location considered. The notched leading-edge fillet caused a reduction in both the tail-off and the trimmed maximum lift coefficients.

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1. Kemp, William B., Jr., Becht, Robert E., and Few, Albert G., Jr.: Stability and Control Characteristics at Low Speed of a $\frac{1}{4}$-Scale Bell X-5 Airplane Model. Longitudinal Stability and Control. NACA RM L9K08, 1950.

2. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA ARR L5G31, 1945.

3. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, With Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Supersedes NACA RM A7B28.)

TABLE I

AERODYNAMIC-CENTER LOCATIONS

Wing plan form	Tail condition	Fuselage station, (in.)	Location of aerodynamic center				
			Percent M.A.C. of plan form shown				
Basic	Off	36.11	28.3	-----	-----	-----	-----
Notched leading edge	Off	36.54	30.1	26.2	15.1	-----	-----
Rounded leading edge	Off	36.56	30.2	-----	-----	26.3	18.0
Basic	$i_t = -\frac{3}{4}°$	39.37	42.0	-----	-----	-----	-----
Notched leading edge	$i_t = -\frac{3}{4}°$	40.01	44.7	41.3	31.8	-----	-----
Rounded leading edge	$i_t = -\frac{3}{4}°$	39.99	44.6	-----	-----	41.3	34.2
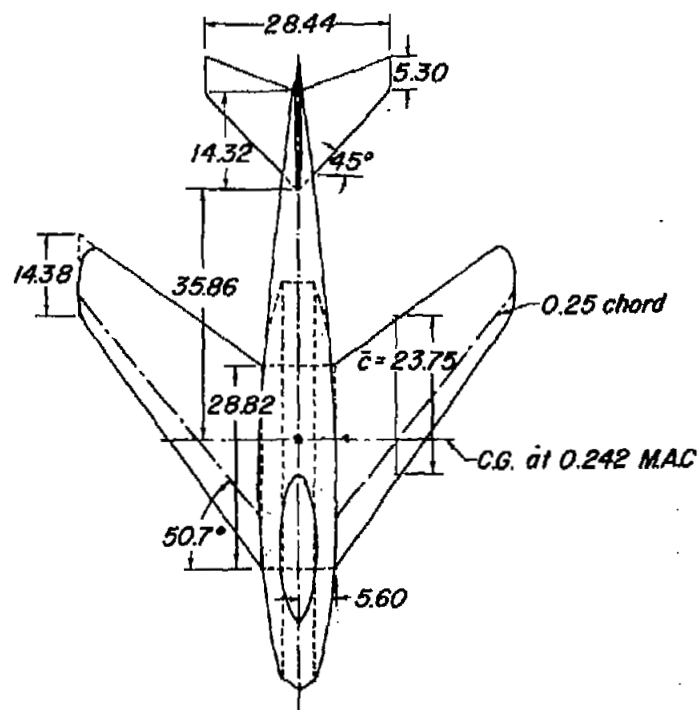
Physical characteristics

Wing

Sweep , deg .	50.7
Area , sq ft	10.80
Aspect ratio	2.98
Span, ft	5.67
Mean aerodynamic chord , ft	1.979
Incidence, deg	0
Dihedral , deg	-2

Airfoil section perpendicular to 0.25c

Root	NACA $64_{(10)}$ – 010.3
Tip	NACA 64–008

Horizontal tail

Area , sq ft	1.94
Aspect ratio	2.89

Vertical tail

Area, sq ft	1.33
Aspect ratio	1.46
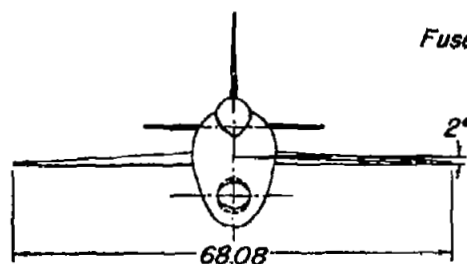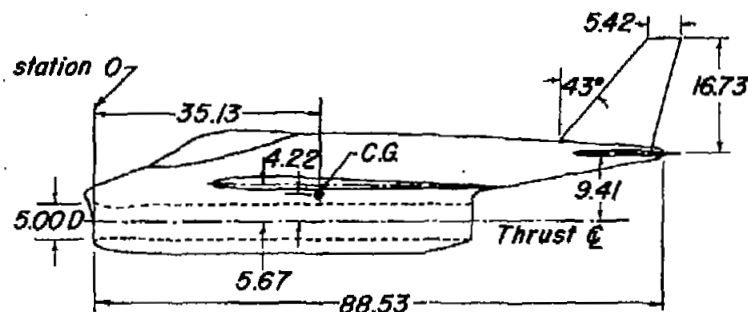
Figure 1.- General arrangement of test model.
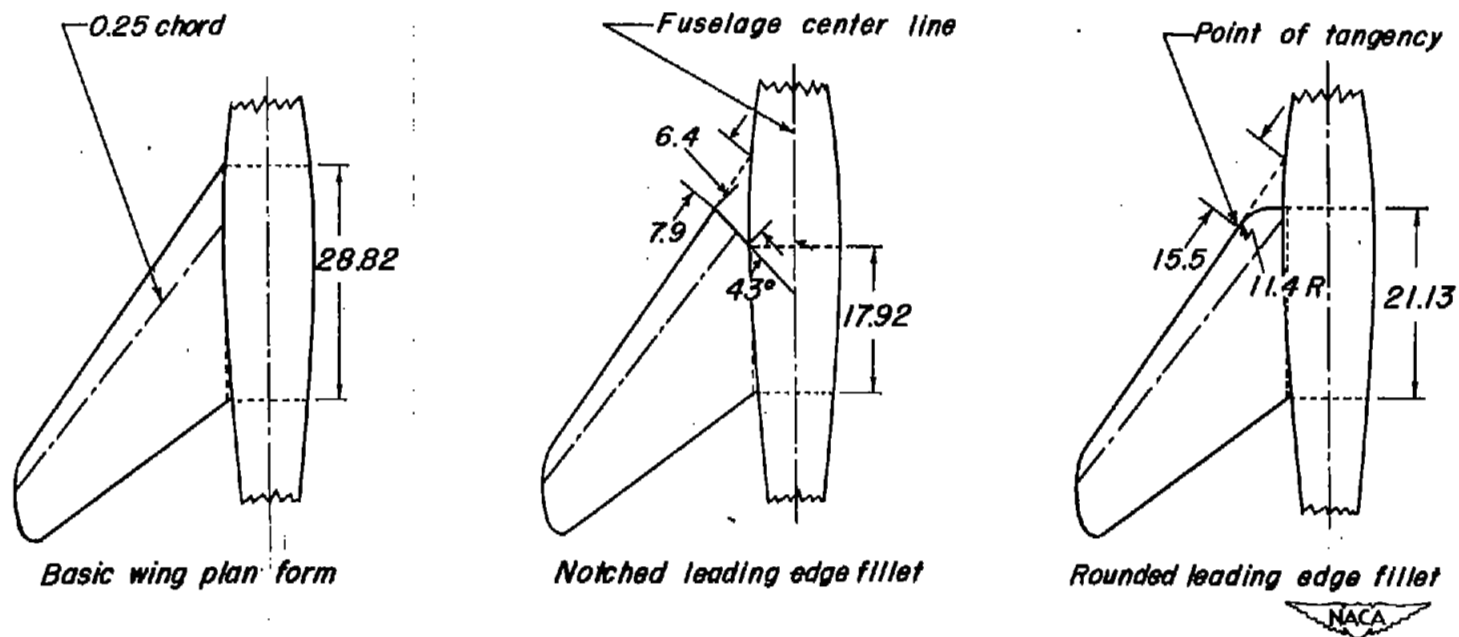
Figure 2.- Details of wing leading-edge fillet modifications. All
dimensions are in inches.
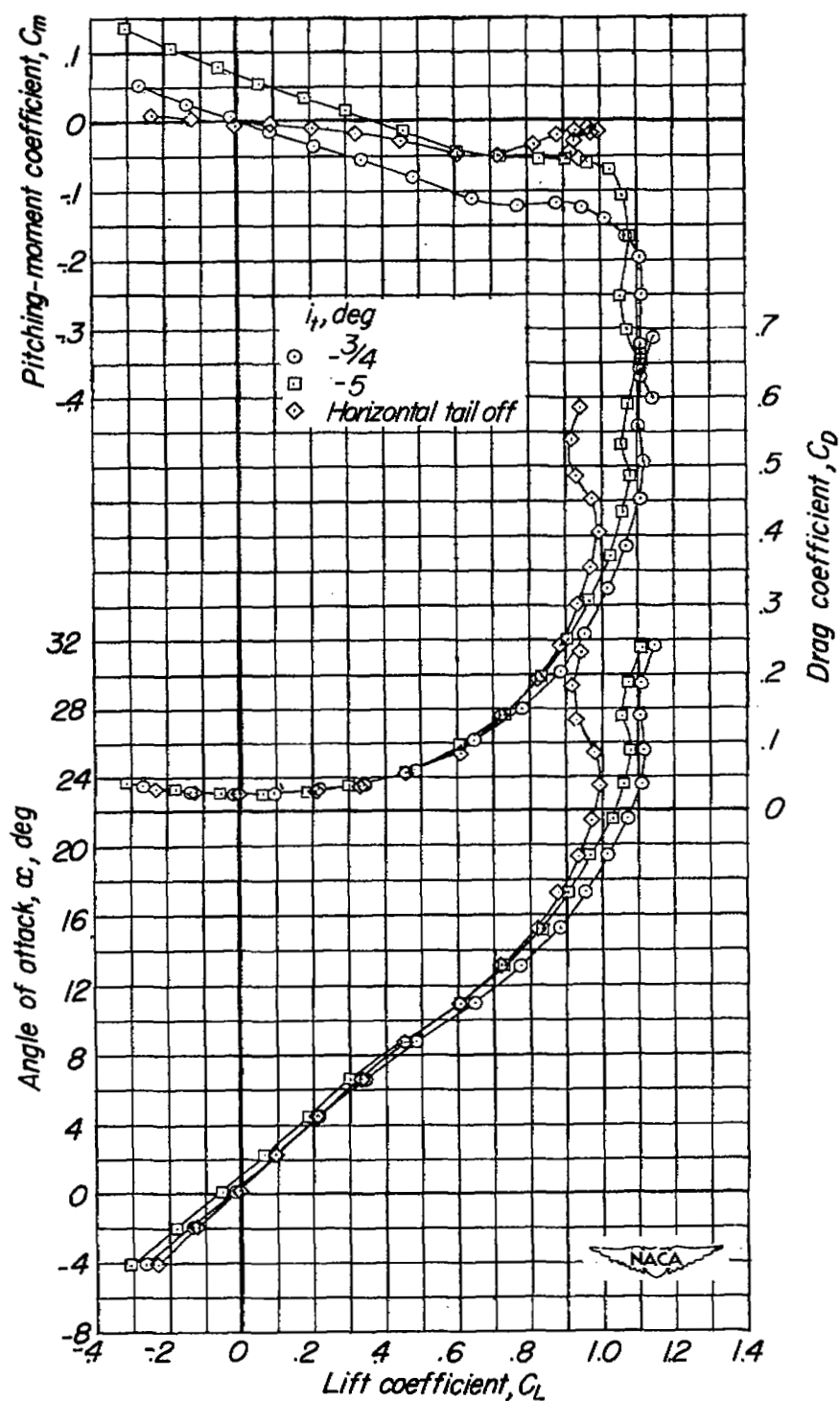
Figure 3.- Longitudinal aerodynamic characteristics of the test model
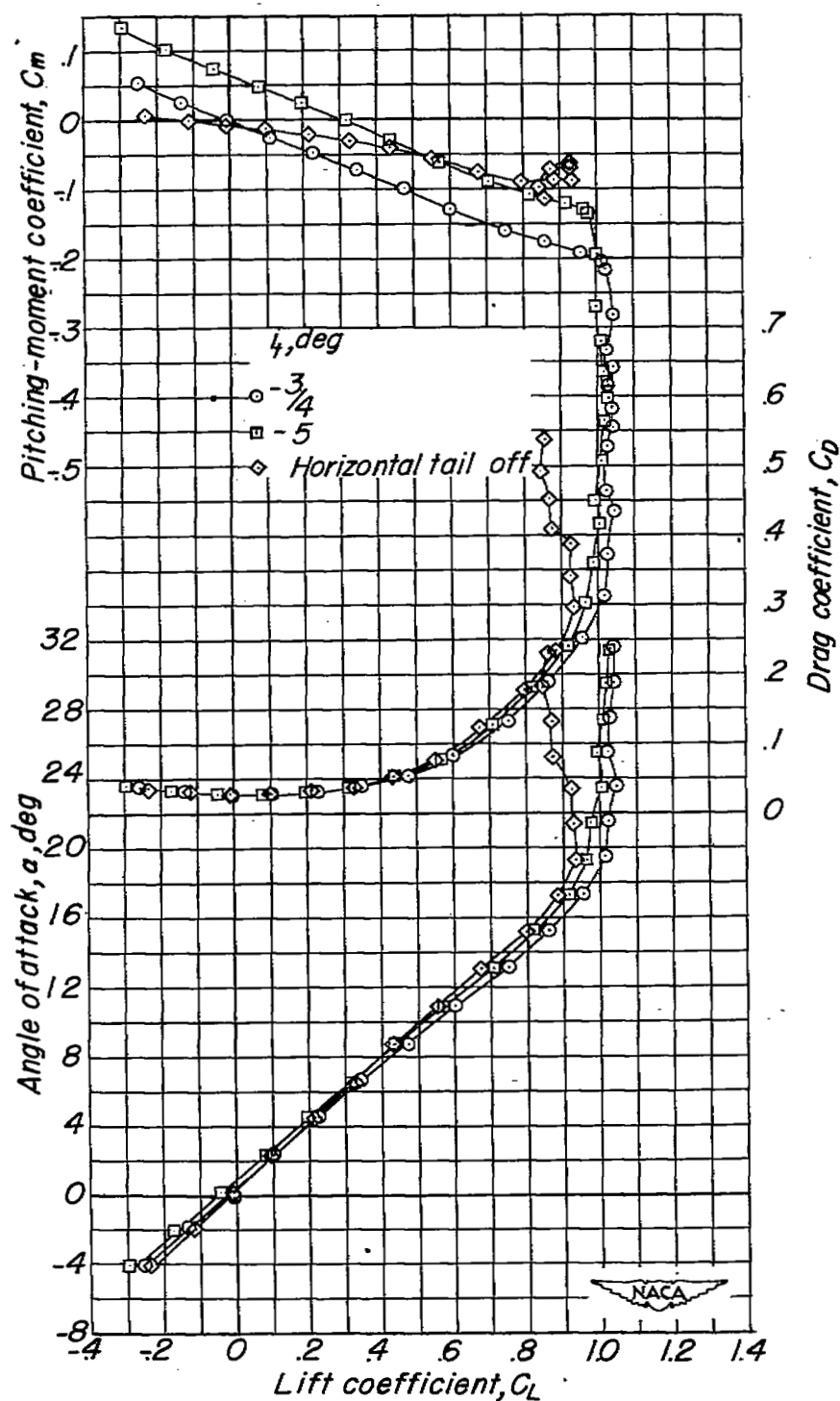with the basic wing plan form.

Figure 4.- Longitudinal aerodynamic characteristics of the test model
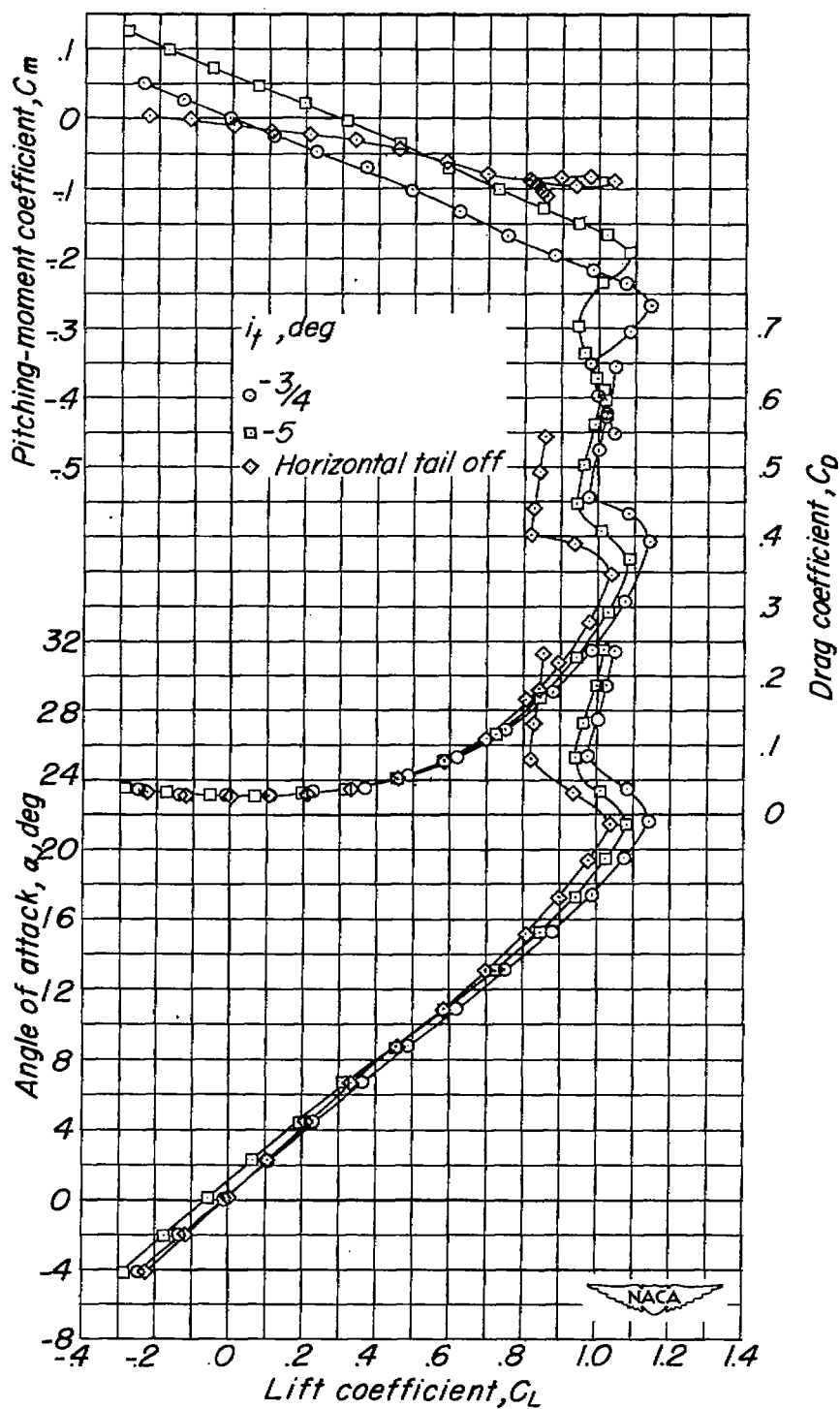with a notched leading-edge fillet.

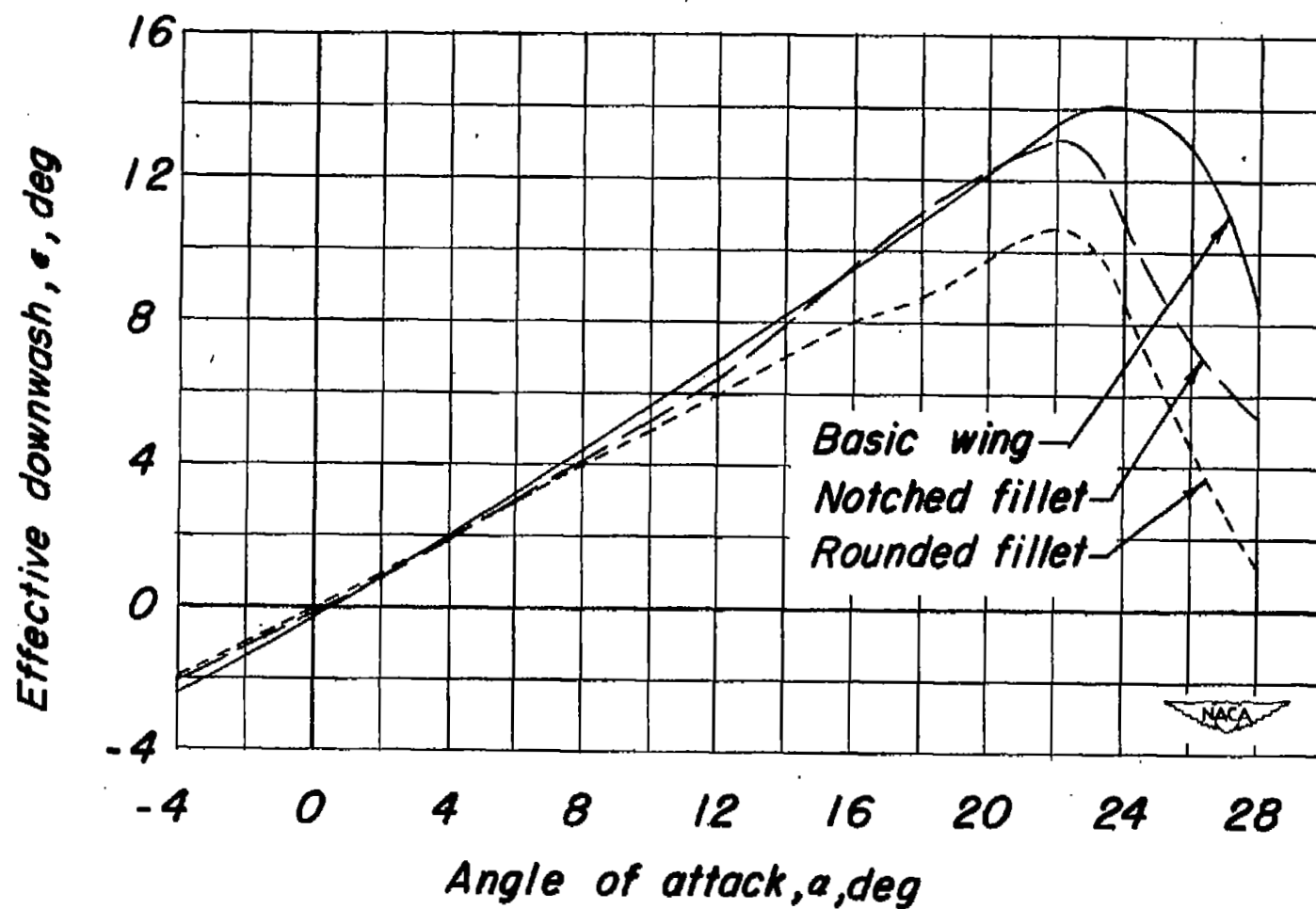Figure 5.- Longitudinal aerodynamic characteristics of the test model with a rounded leading-edge fillet.

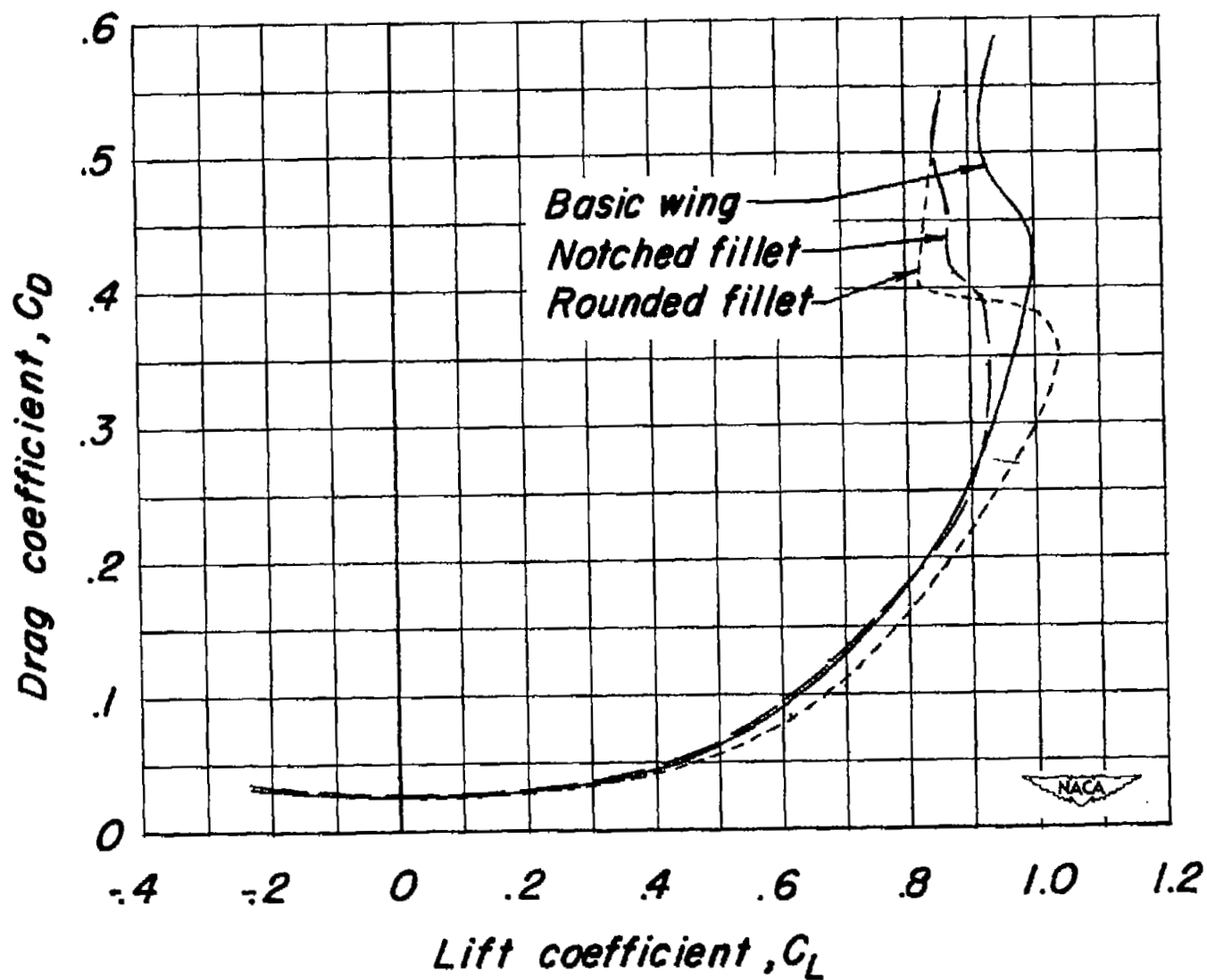Figure 6.- Effect of leading-edge fillets on the effective downwash at
the tail.

Figure 7.- Effect of leading-edge fillets on the tail-off drag polar.